Surface BRF studies at Railroad Valley (RRV)

CEOS WGCV IVOS 31

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With additional acknowledgements

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MODIS surface BRF: Crystal Schaaf[5], Arthur Elmes[5]

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Study objectives

- Given that surface reflectance is the dominant contributor to the top-of-atmosphere (TOA) radiance incident on a sensor, and given that this varies as a function of view angle, surface bi-directional reflectance function (BRF) is an important characteristic of a Vicarious Calibration (VicCal) test site.
- OCO-2 has used the MODIS MCD43A1 surface BRF product to adjust in-situ measurements for off-nadir sensor views.
  - PARABOLA data and off-nadir field spectrometer data have been used to validate the MODIS data product
- The validation data can be used to answer basic questions relating to the BRF at Railroad Valley (RRV)
  - How non-Lambertian is RRV?
  - How does this vary in time and space?
  - Can a representative BRF be defined, specific to a given test site?
  - How accurate are space-based determinations of surface BRF?

Terminology

- The surface reflectance used for OCO-2 VicCal[1] is computed from

  BRF(θsza,ϕsza; θsza,ϕsza) = BRF_asd(θsza,ϕsza; 0º,0º) * normBRF, where

  normBRF=BRF_modis(θsza,ϕsza ; θsza,ϕsza)/BRF_modis(θsza,ϕsza 0º,0º)

- BRF_asd are nadir-viewing surface reflectances, measured during field-campaigns (or obtained from RadCalNet)
- normBRF is the adjustment term to the measured in-situ data
  - It varies slowly with wavelength, thus spectral differences between the BRF-measuring sensor and the sensor to be calibrated are not error contributors
- The differences between HDRF (diffuse-sky illumination) and BRF (a property of the surface only) are understood, but assumed negligible at RRV, due to low aerosol conditions
  - BRF is preferred to BRDF, as it is a unitless parameter
  - See Backup for a further discussion

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1. C.J. Bruegge, D. Crisp, M.C. Helmlinger, F. Kataoka, A. Kuze, R. A. Lee, J.L. McDuffie, R.A. Rosenberg, F.M. Schwandner, K. Shiomi, and S. Yu., "Vicarious Calibration of Orbiting Carbon Observatory-2 (OCO-2)," IEEE Trans. Geosci. and Remote Sens., pp 1-11, early access publication March 20, 2019, **DOI:** 10.1109/TGRS.2019.2897068

In-situ BRF measurement approaches

- Dedicated instruments
  - A. Scanning radiometer: PARABOLA
  - B. Goniometer: ULGS-2
- Ad hoc approaches
  - C. Off-nadir transects
  - D. Off-nadir azimuthal scans

C. Off-nadir transects

A. PARABOLA (JPL)

B. ULGS-2 goniometer

D. Azimuthal scans

A. PARABOLA

- The Portable Apparatus for Rapid Acquisition of Bidirectional Observation of Land and Atmosphere (PARABOLA) instrument measures surface off-nadir reflectance throughout the day
- A Spectralon tile is placed in the nadir-viewing angle, in order to compute at all view angles (except nadir)
- The installation of masts, in 2013, at four RRV locations permits easy setup during field campaigns

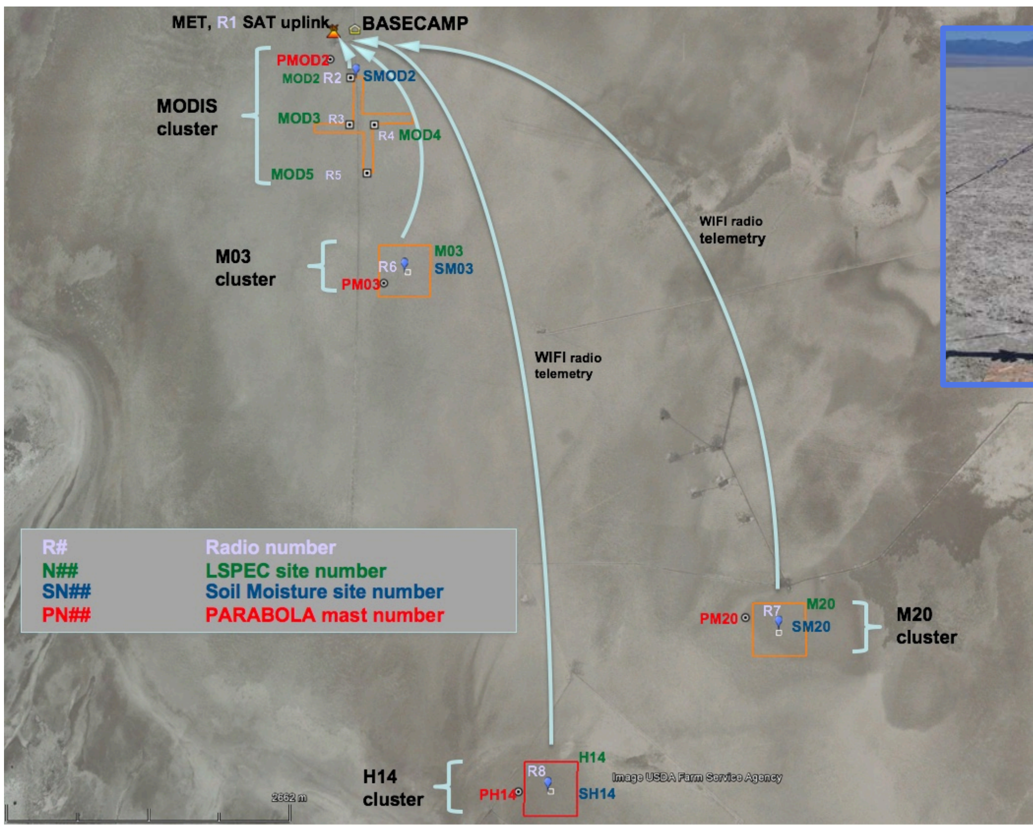
Spectralon is viewed once per scan

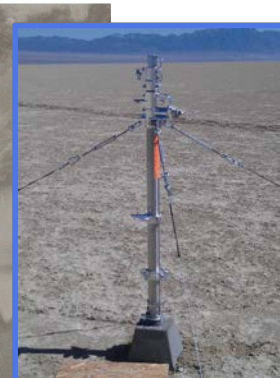
PARABOLA mast setup prior to 2013. Cover: current setup procedure makes use of pre-installed masts

PARABOLA, cont.

Features

- 2664 spatial samples (37 x 72) in 3.3 minutes
- Eight spectral bands: 444, 551, 581, 650, 860, 944, 1028, and 1650 nm
- Passbands range from 30 to 300 nm for the PAR channel 400-700 nm at 581 nm
- 5° field-of-view; nadir 0.33 m (1 ft) footprint at 3.6 m (12 ft) height
- Silicon and germanium (for 1028 and 1650 nm) detectors, TEC oooled to -10 C
- 21 datasets collected 2011-2018

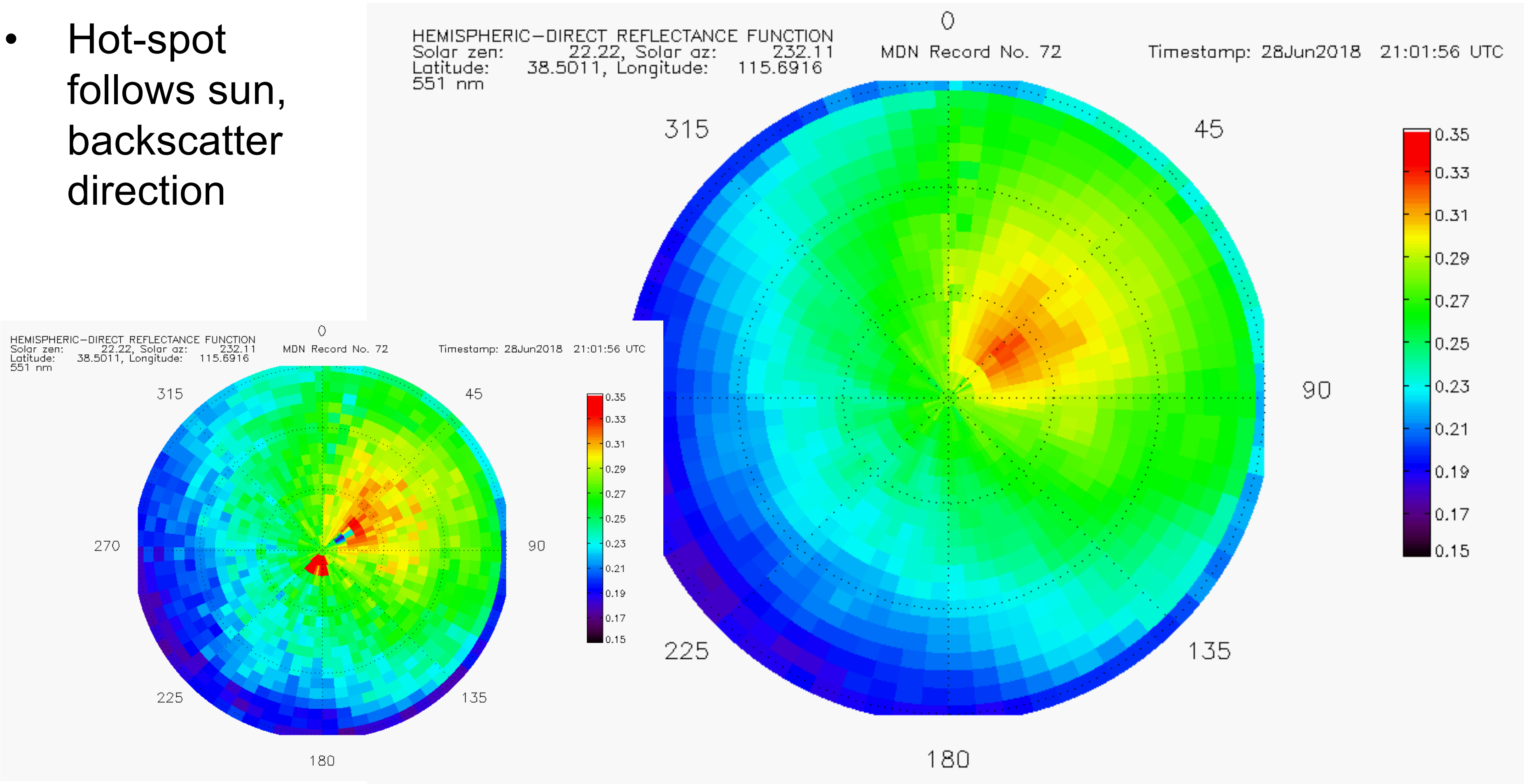




Mast locations: MDN (north MODIS), M03, M20, H14

Output polar plots

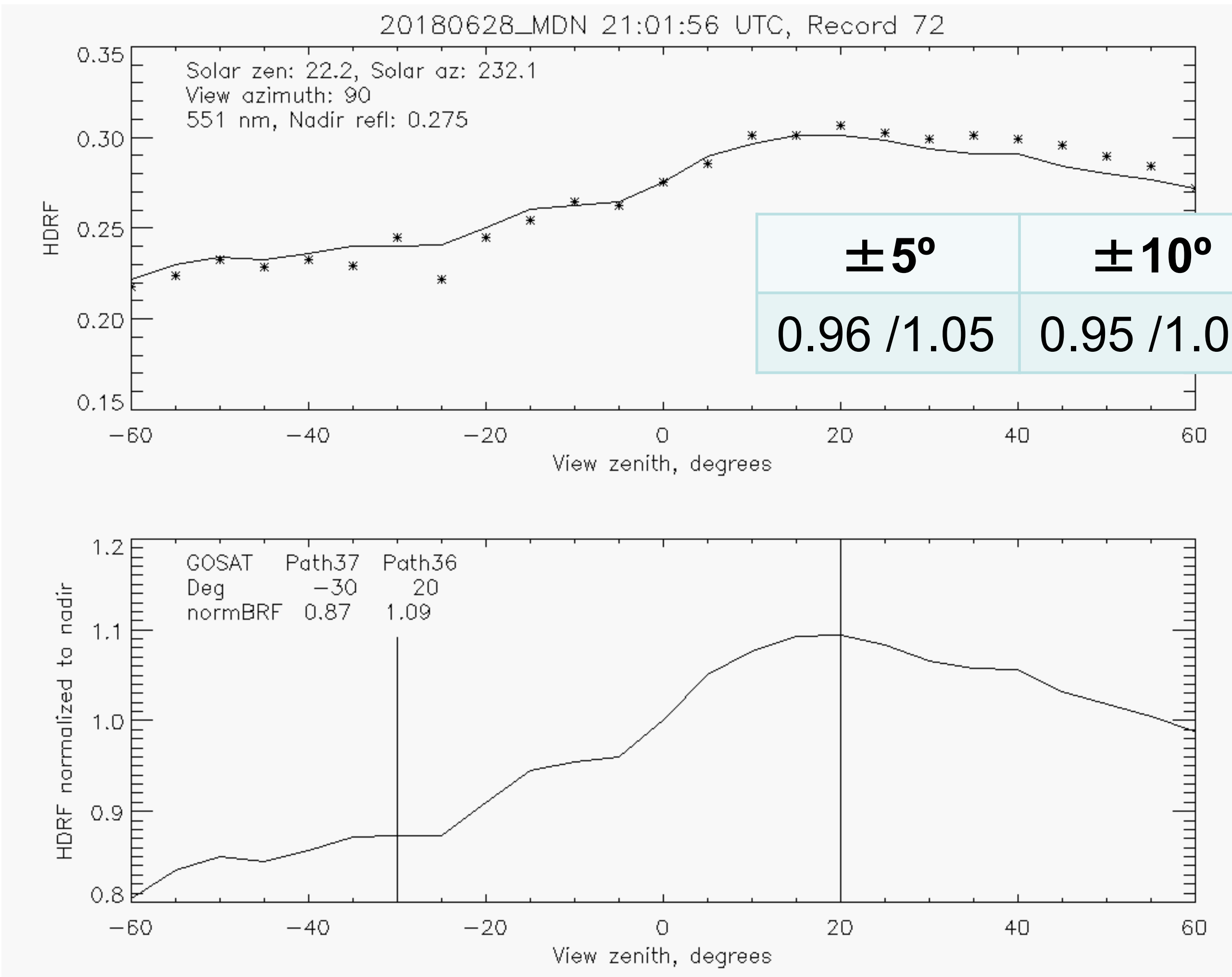
- Hot-spot follows sun, backscatter direction



Left) Original reflectance measurements. Right) Processing includes removal of Spectralon panel, mast shadows. Then took an average of symmetry of hemispheres, by averaging data on both sides of principal plane. Final step: sliding 5x5 smoothing.

Output line plots: 28May2018 21:00 UTC, MDN

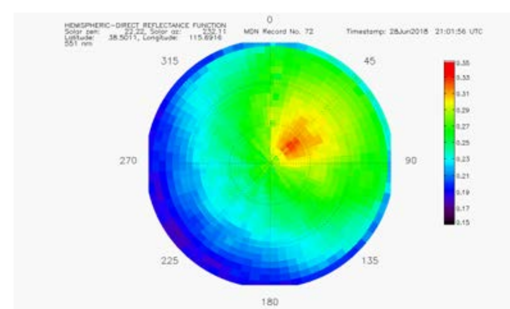
- Comparison facilitated by two metrics: 1) normBRF in East-West azimuth (this is the GOSAT view direction), 2) maximum normBRF. 21:00 UTC baseline time (average time for 2 GOSAT overpass paths).



normBRF

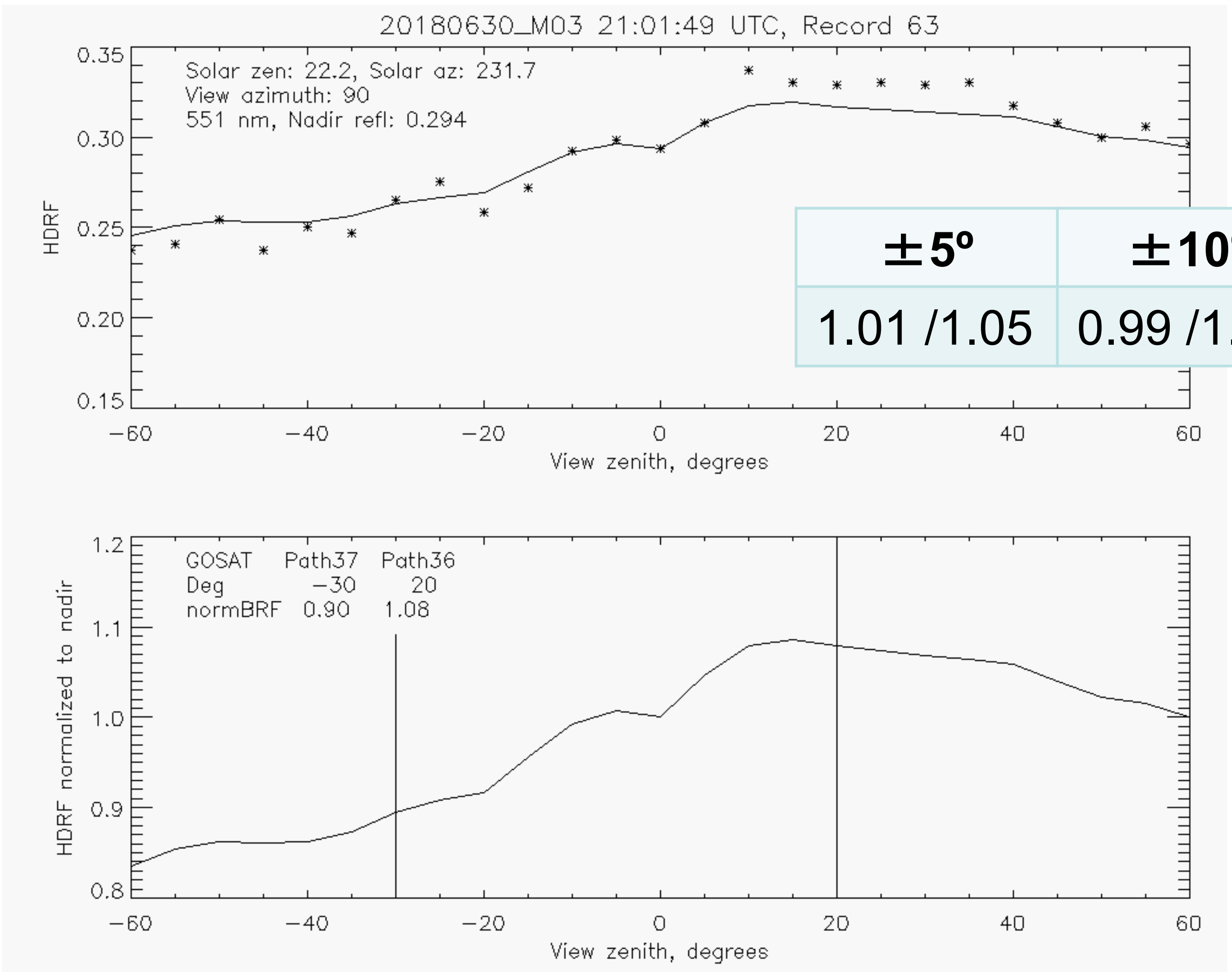
±5º	±10º	±20º	±30º
0.96 /1.05	0.95 /1.08	0.91 /**1.09**	**0.87** /1.07

maz(normBRF) =1.18



Output line plots: 30May2018 21:00 UTC, M03

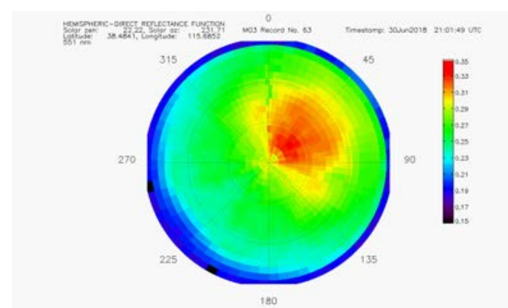
- Comparison facilitated by two metrics: 1) normBRF in East-West azimuth (this is the GOSAT view direction), 2) maximum normBRF. 21:00 UTC baseline time (average time for 2 GOSAT overpass paths).



normBRF

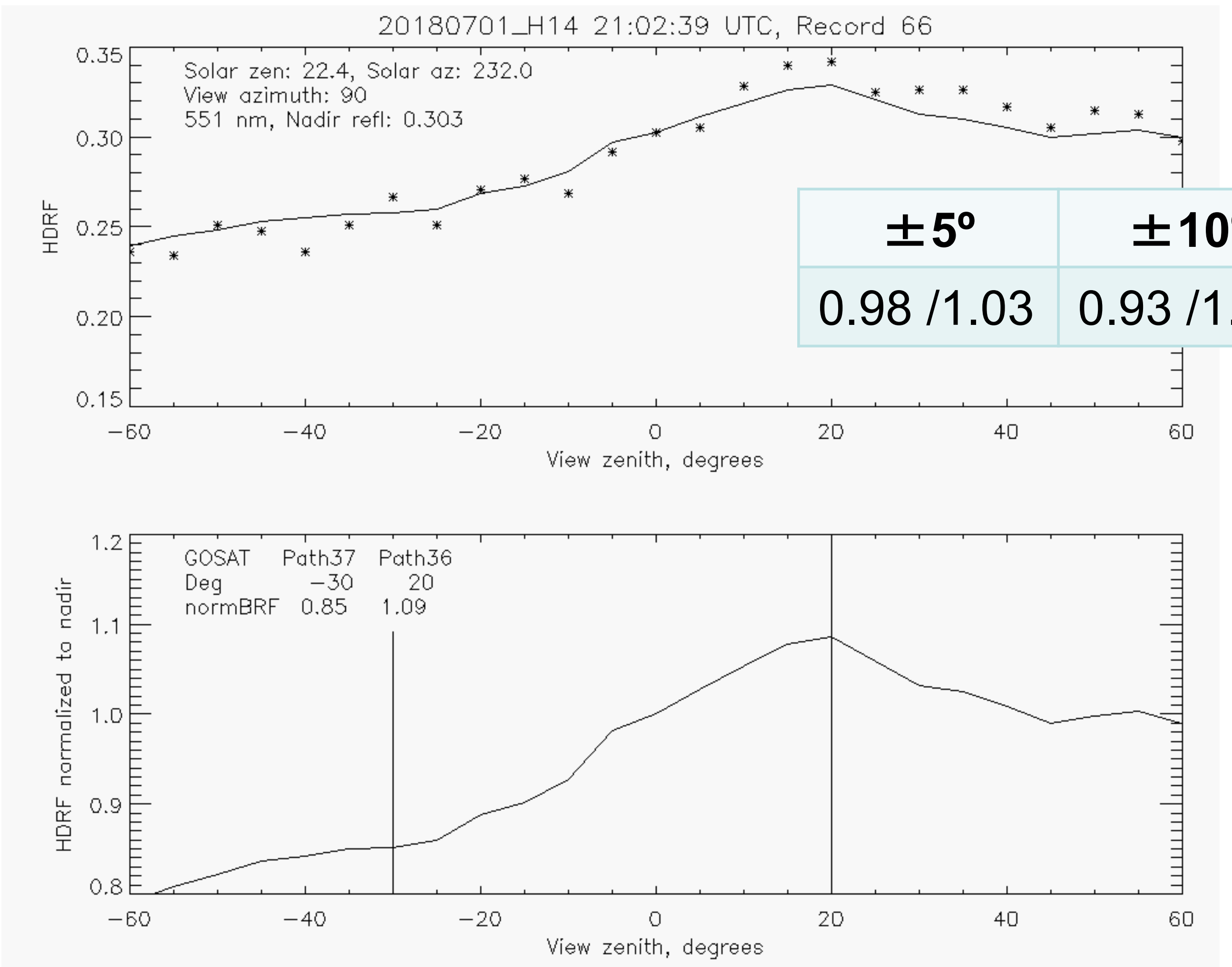
±5º	±10º	±20º	±30º
1.01 /1.05	0.99 /1.08	0.92 /**1.08**	**0.90** /1.07

maz(normBRF) =1.15



Output line plots:
01Jun2018 21:00 UTC, H14

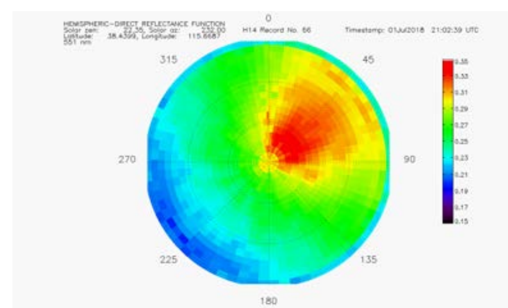
- Comparison facilitated by two metrics: 1) normBRF in East-West azimuth (this is the GOSAT view direction), 2) maximum normBRF. 21:00 UTC baseline time (average time for 2 GOSAT overpass paths).



normBRF

±5º	±10º	±20º	±30º
0.98 /1.03	0.93 /1.05	0.89 /**1.09**	**0.85** /1.03

maz(normBRF)
=1.15



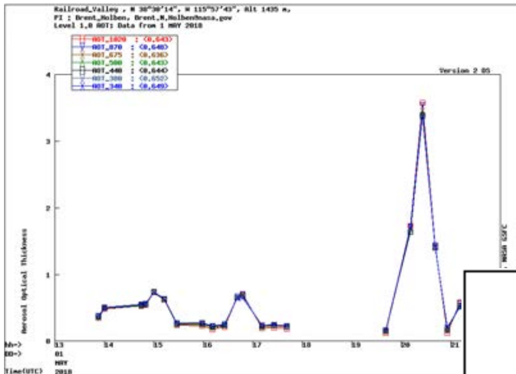
Field trip: May 2018

Participants

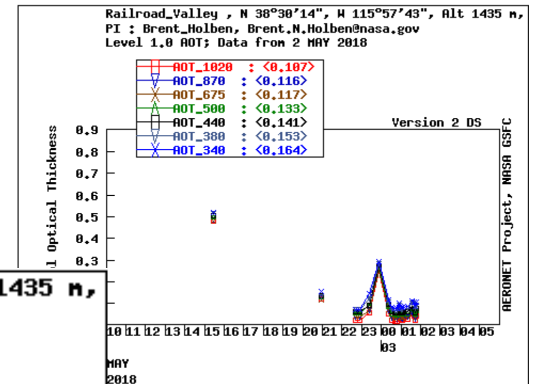
- NASA/GSFC
- University of Arizona
- NASA/JPL
- University of Lethbridge
- AIST Japan
- DigitalGlobe/Radiant Solutions

Sky conditions during May site visit

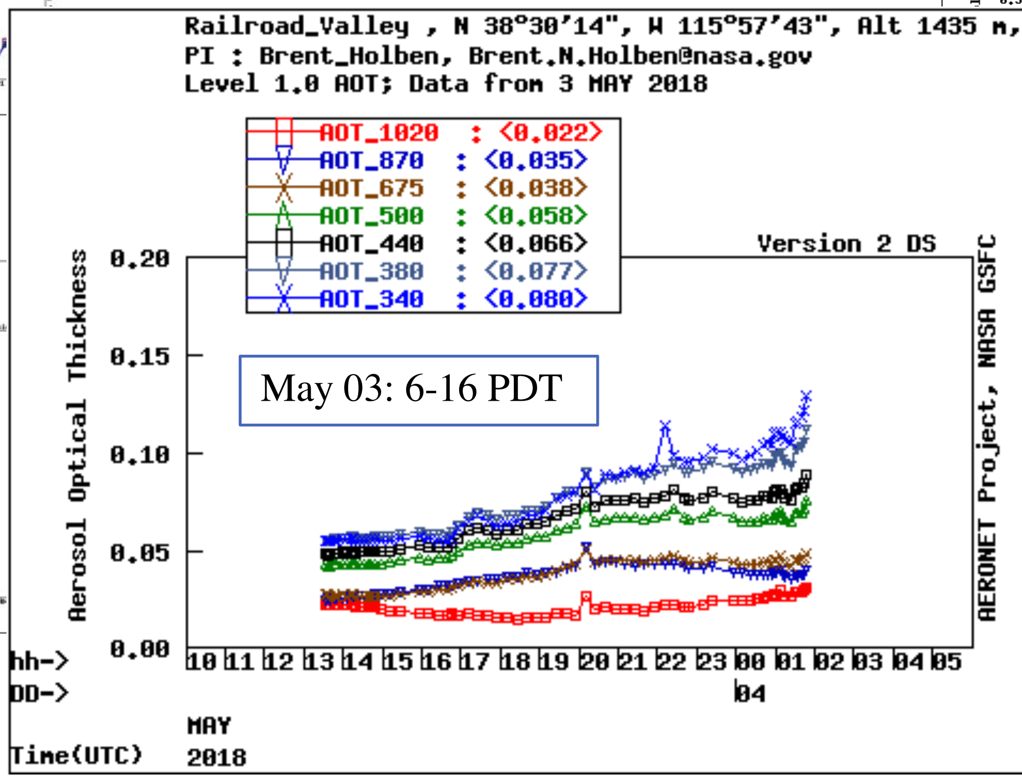
Times of day where AOD(550nm) < 0.1



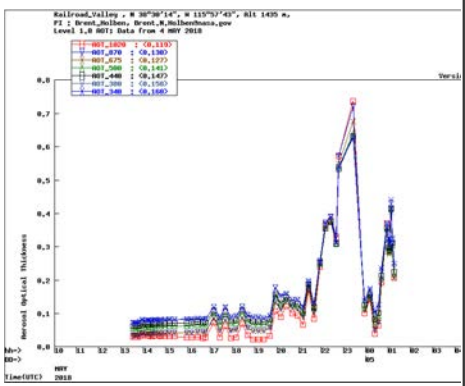
May 01: None (cloudy)



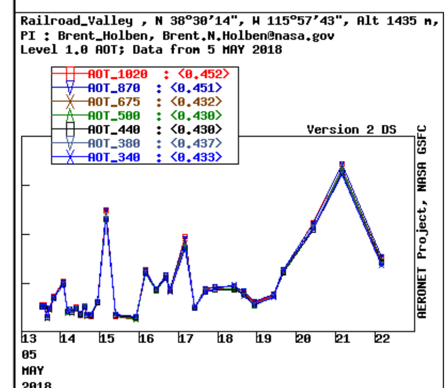
May 02: Clearing after 17:00 PDT



May 03: 6-16 PDT



May 04: 6-13 PDT

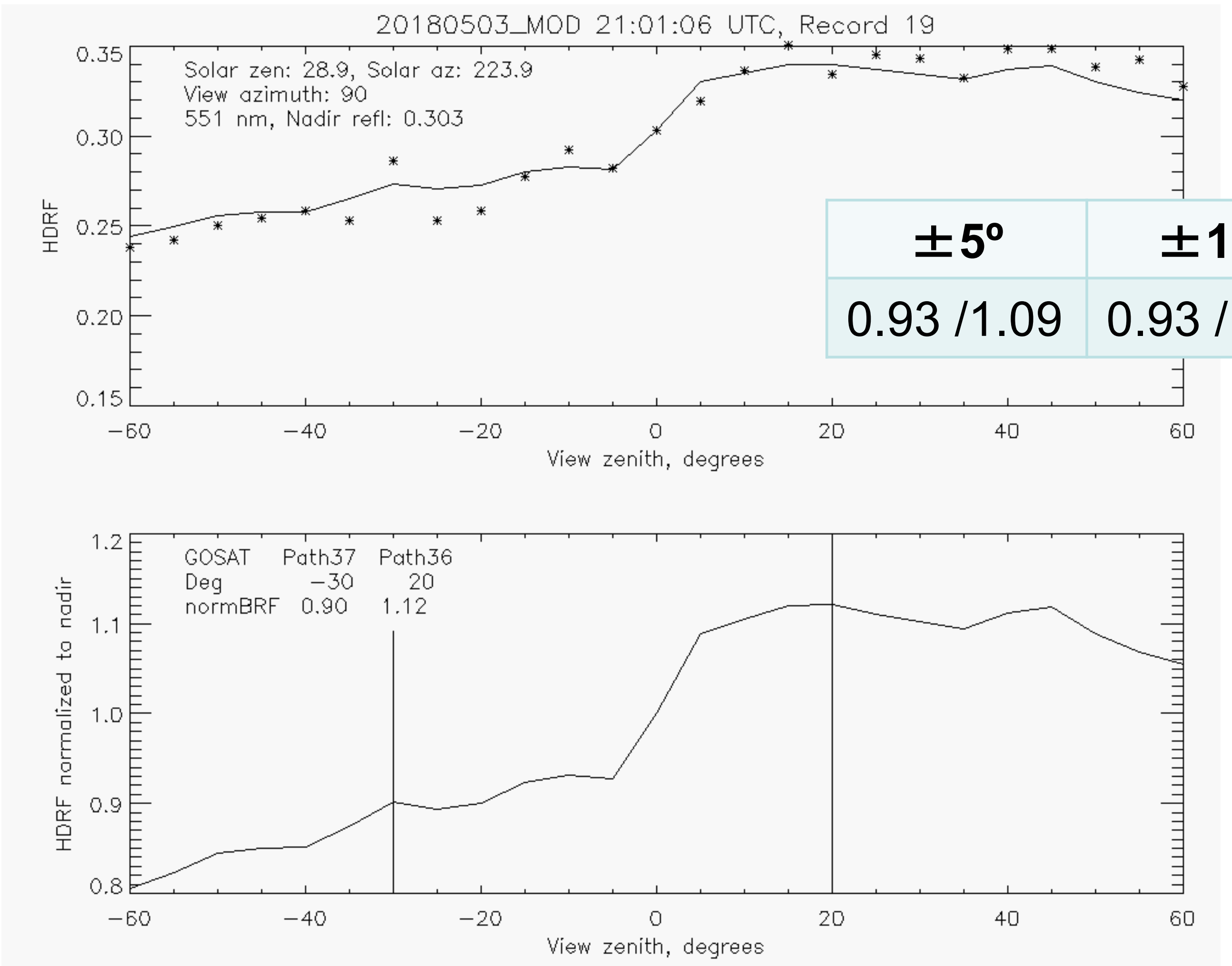


May 05: None (cloudy)

May 03 "Golden Day"

Line plots: 03May2018 21:00 UTC, MDN

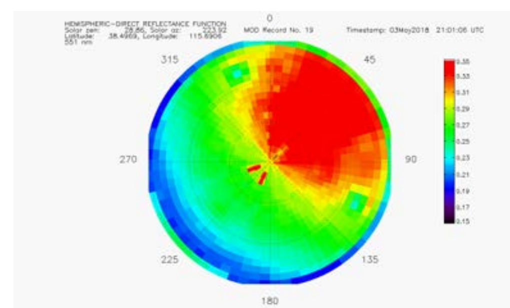
- Larger normBRF at GOSAT overpass times --- not because surface changed, but because sun is lower (higher θzen for a fixed overpass time).



normBRF

±5º	±10º	±20º	±30º
0.93 /1.09	0.93 /1.11	0.90 /**1.12**	**0.90** /1.10

maz(normBRF)
=1.24



B. ULGS-2 goniometer

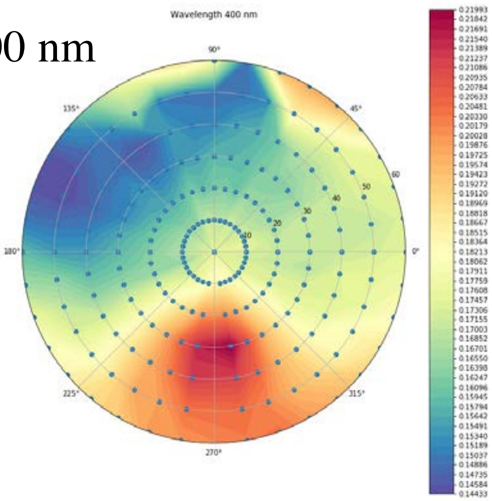
- Features
  - Goniometer: Ocean Optics USB-4000
  - Dual: Identical Ocean Optics unit measures downwelling
  - 64 spectral bands: 400-1000 nm in 10 nm steps
  - 8º field-of-view; nadir tbd 30 cm (1 ft) footprint on a 2 m (6.5 ft) arc
  - ASD FieldSpecPro measures nadir reflectance, 350-2500 nm, 8º FOV at 1 m height above ground
- Processing steps
  - Screen data for bad samples (Gershun tube reflectances, ...)
  - Arc shadow used to identify SPP, then these are removed
  - Rotate such that principal plane is in up/ down orientation (90º/ 270º).
    - Down=backscatter direction (and increased reflectance)
  - Create ratio upwelling/ downwelling light from goniometer (ocean optics data)
    - Downwelling sensor is looking through a (Spectralon) cosine receptor
  - Scale data such that the goniometer data agrees with the ASD data at nadir.
    - Scalar is spectrally dependent, but applied at all view angles
- Data collects
  - 03May2018: 19 collects 14:30 – 22:27 UTC (7:30 – 15:00 PDT)
  - Daily collects 01May2018 - 05May2018, with questionable cloud cover

Craig's polar plots
03May2018 21:06 UTC, MOD

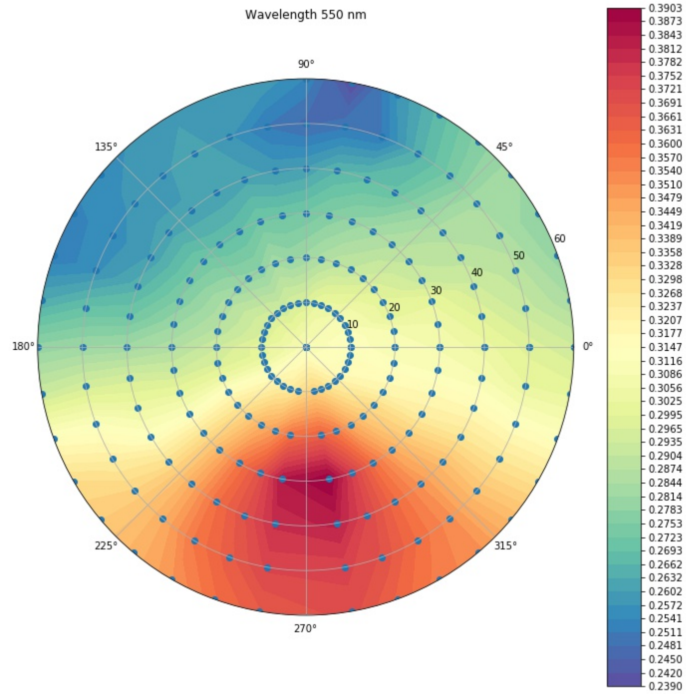
May03_2018:May03_2018-20:58/ASD Calibrated Polar Plots

- Data rotated so that 90º is forward scatter direction

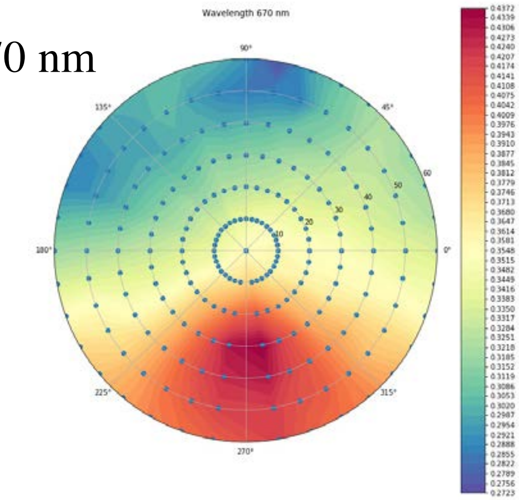
400 nm



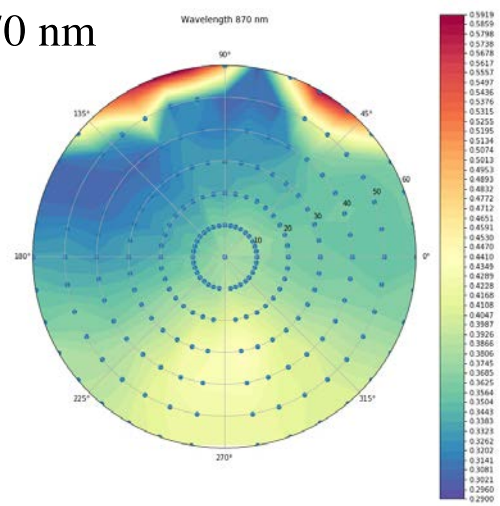
550 nm

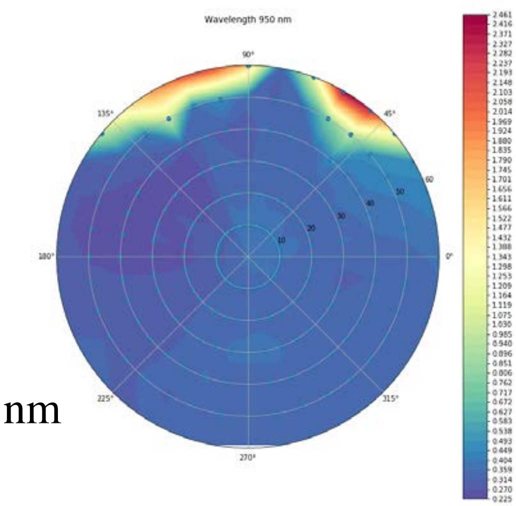


670 nm



870 nm



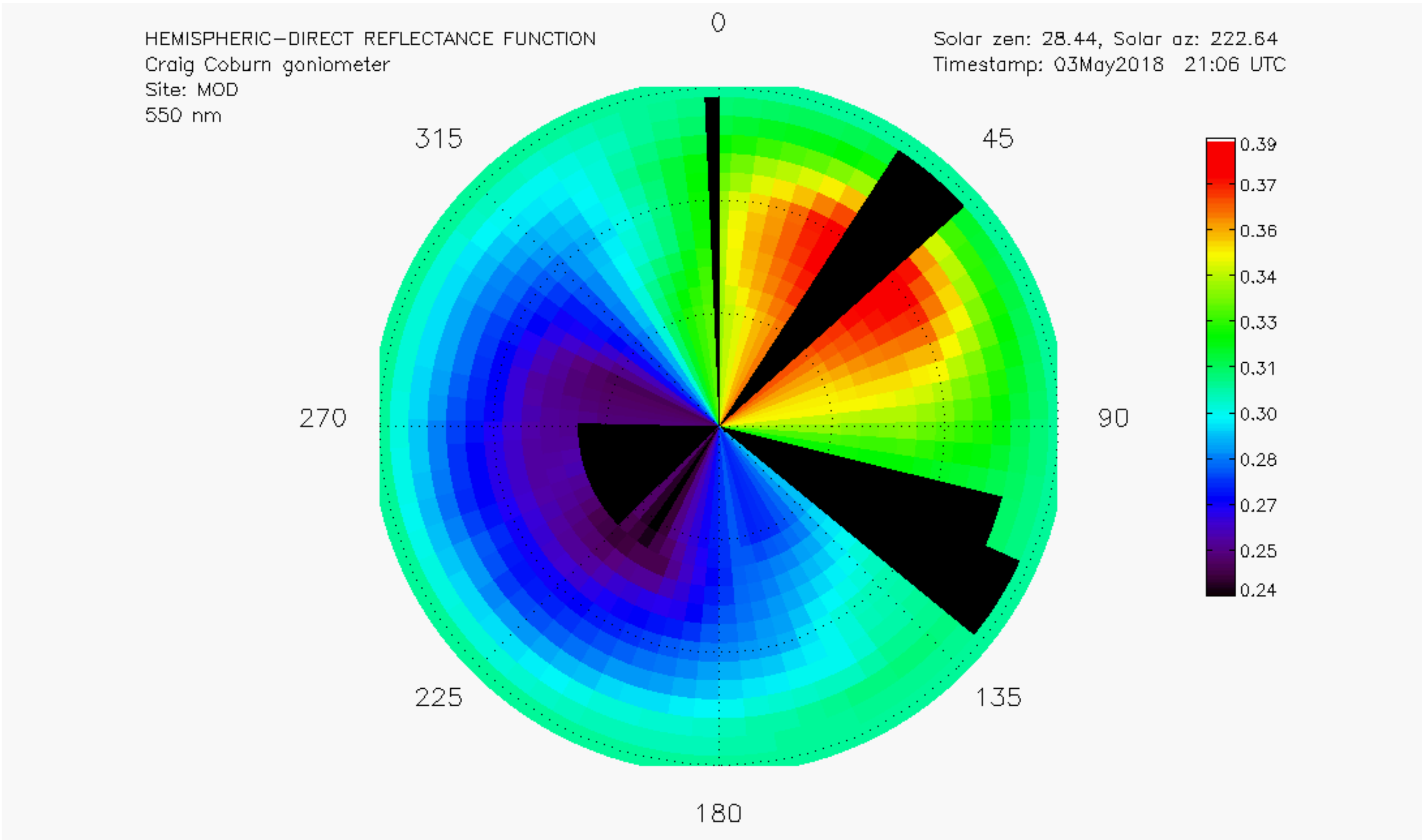


950 nm

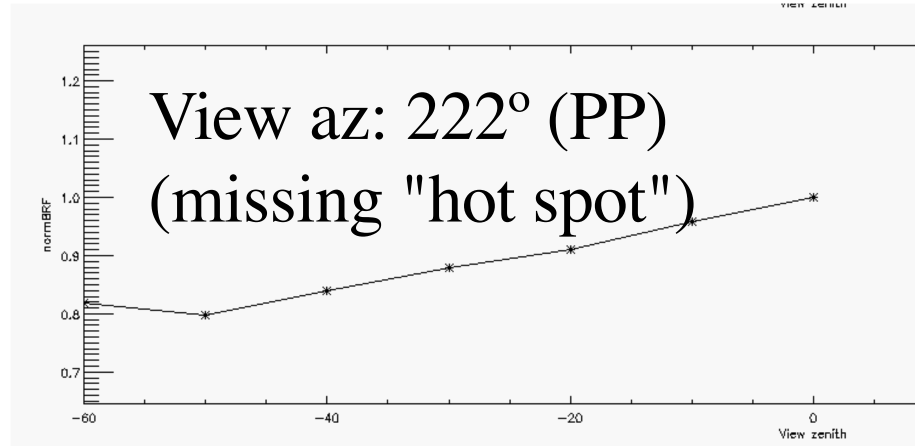
Original data
03May2018 20:58 UTC, MOD

May03_2018:May03_2018-20:58/ASD Calibrated Dataset/asd_calibrated_dataset.csv

- Data rotated so that 0º is view to North



03May2018 20:28 UTC, MOD

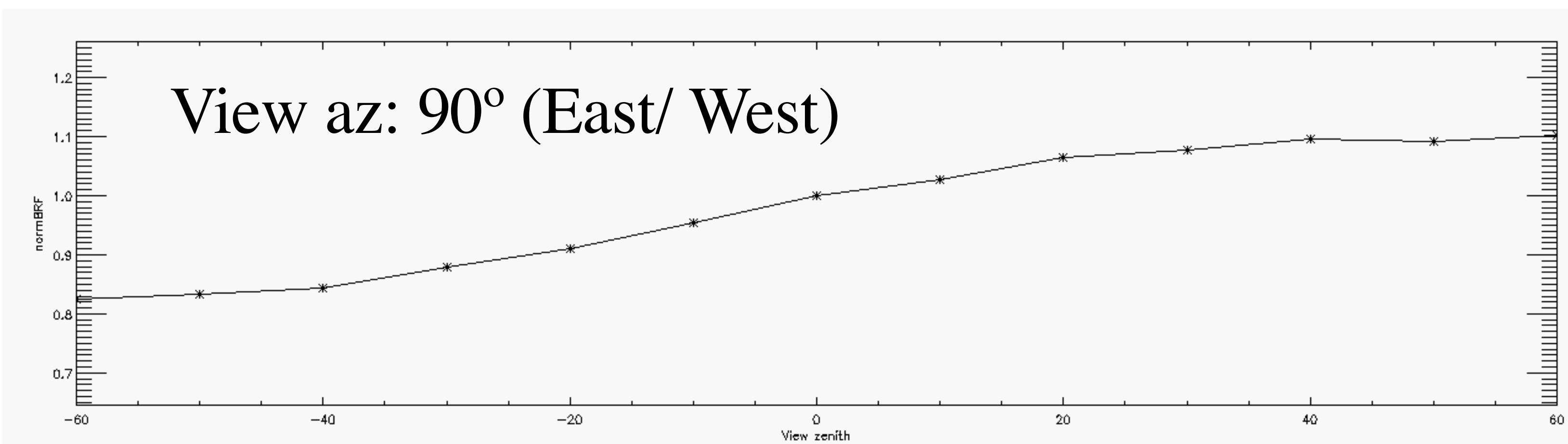


Solar zen: 28.4   Solar az: 222.8

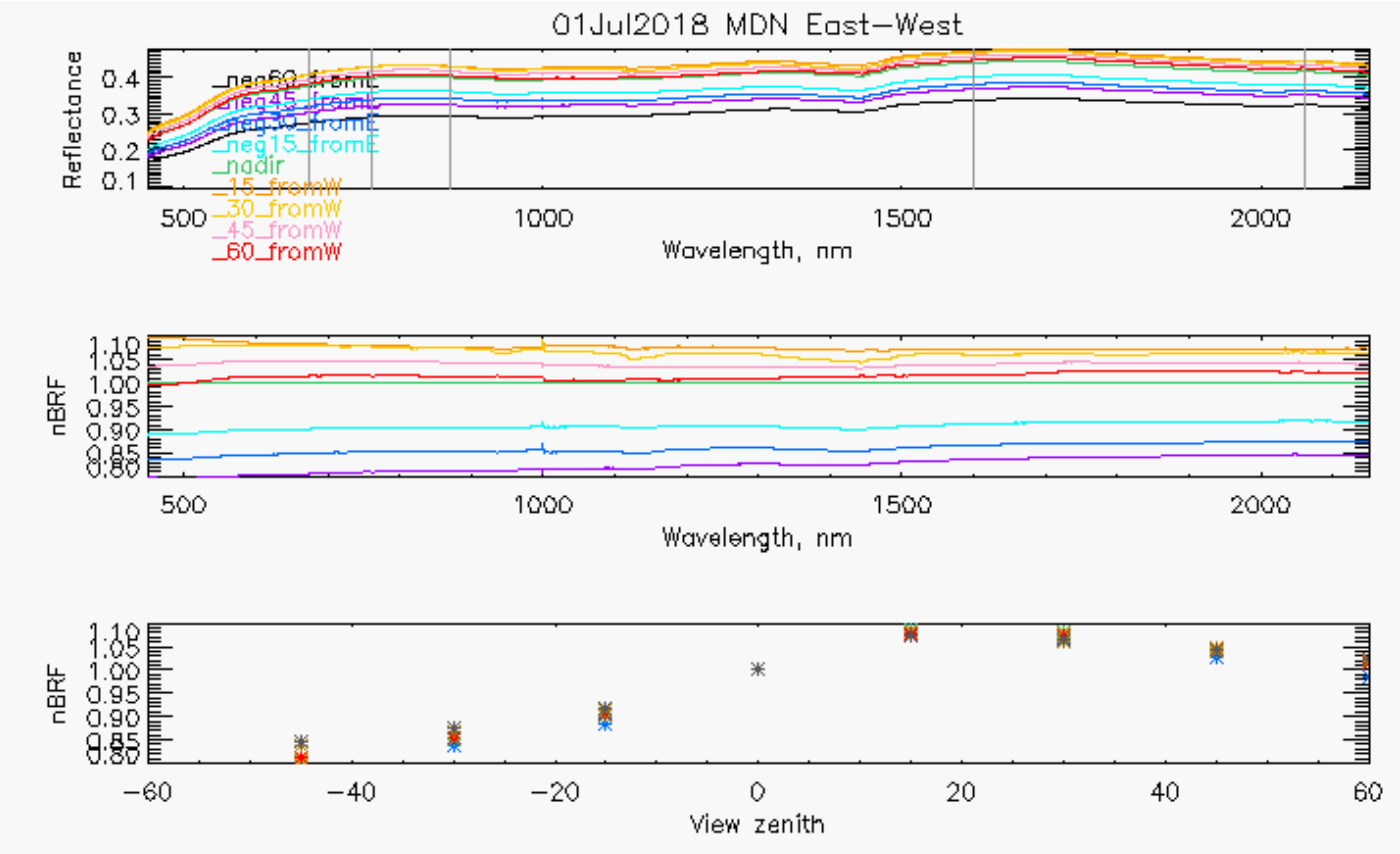
550 nm, Nadir refl: 0.310

maz(normBRF)=1.25

±10°	±20°	±30°
0.95 /1.03	0.91 /**1.06**	**0.88** /1.08



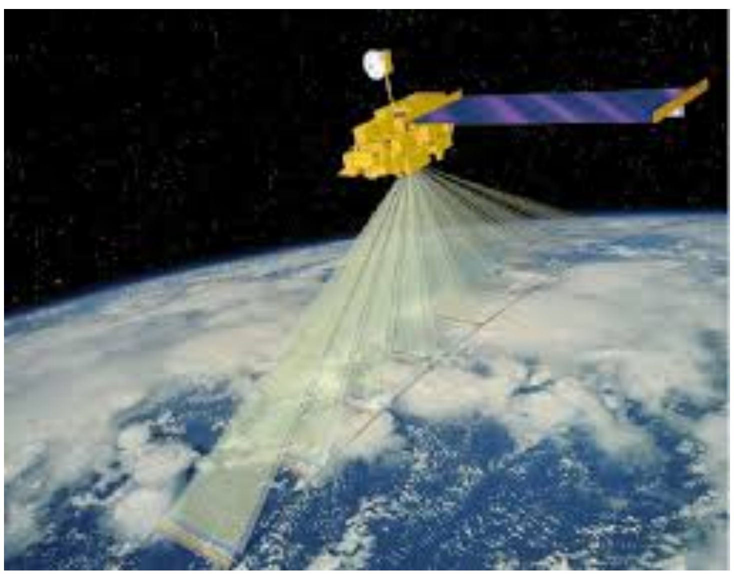
C. Off-nadir transects



BRF determination from on-orbit sensors

Data sources

- MODIS MCD43A1 (or VIIRS alternative)
  - Terra and Aqua combined product
  - 16-day sliding window
  - RossThick-LiSparse Reciprocal model: f_iso, f_vol, f_geo
- EOS/ Terra/ Multi-angle Imaging Spectroradiometer (MISR)
  - 9 cameras allow BRF retrieval specific to each collect
  - Modified Rahman model with fit parameters r_o, k, and b responsible for amplitude, shape, and hot spot area



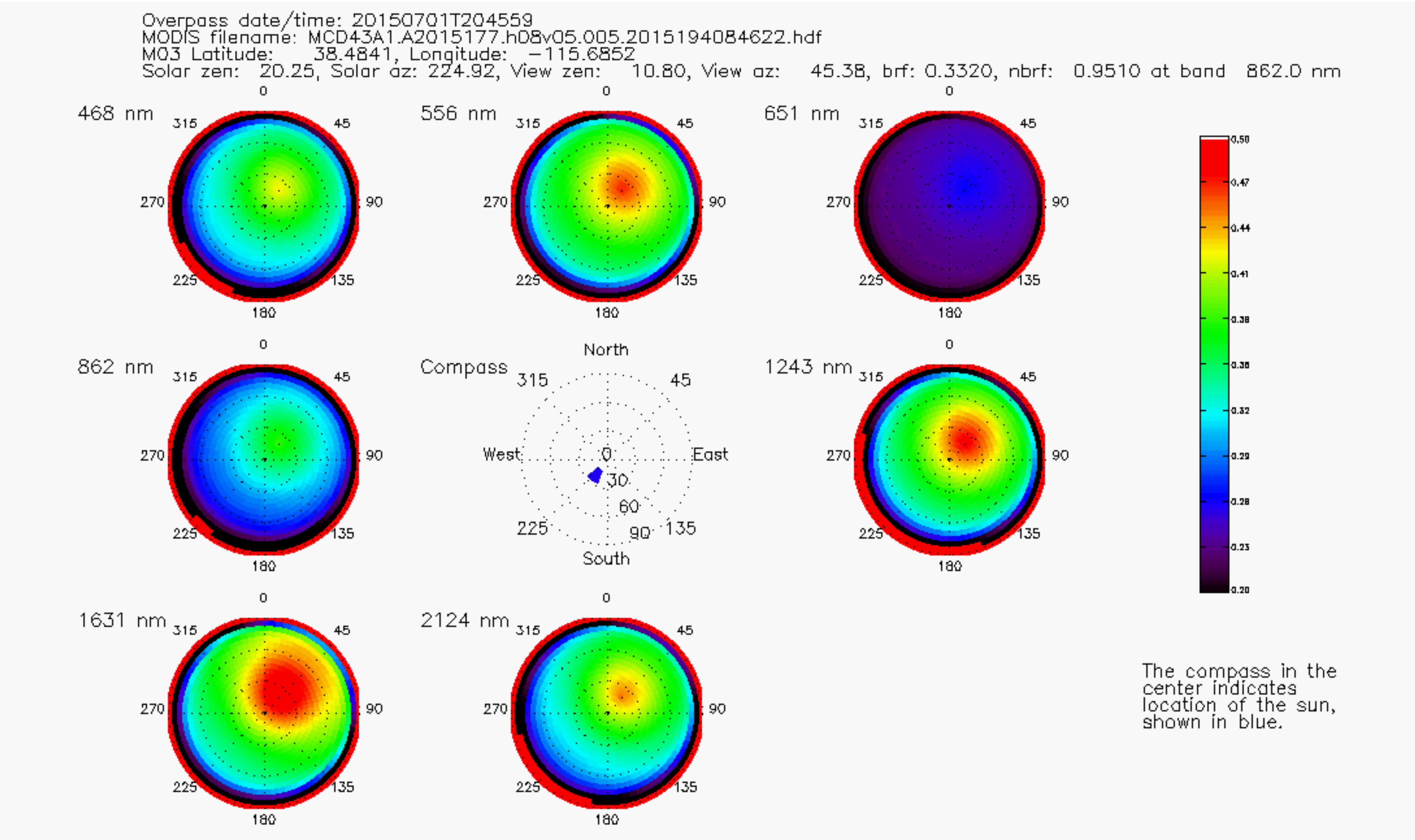
$$R(\theta_0,\theta,\phi) = r_0 \left(\cos\theta \cos\theta_0 (\cos\theta + \cos\theta_0)\right)^{k-1} h \exp(-b\cos\xi)$$

$$h(\theta_0,\theta,\phi) = 1 + \frac{1-r_0}{1+G(\theta_0,\theta,\phi)}$$

$$G(\theta_0,\theta,\phi) = \sqrt{\tan^2\theta + \tan^2\theta_0 - 2\tan^2\theta \tan^2\theta_0 \cos\phi}$$

$$\cos\xi = \cos\theta\cos\theta_0 + \sin\theta\sin\theta_0\cos\phi$$

MODIS BRF product



Data quality flag (MCD43A2)

MODIS QA flag, BRDF_Albedo_Band_Quality_Band1-7:

0 = best quality, full inversion (WoDs, RMSE majority good)

1 = good quality, full inversion (also including the cases that no clear sky observations over the day of interest or the Solar Zenith Angle is too large even WoDs, RMSE majority good)

2 = Magnitude inversion (numobs >=7)

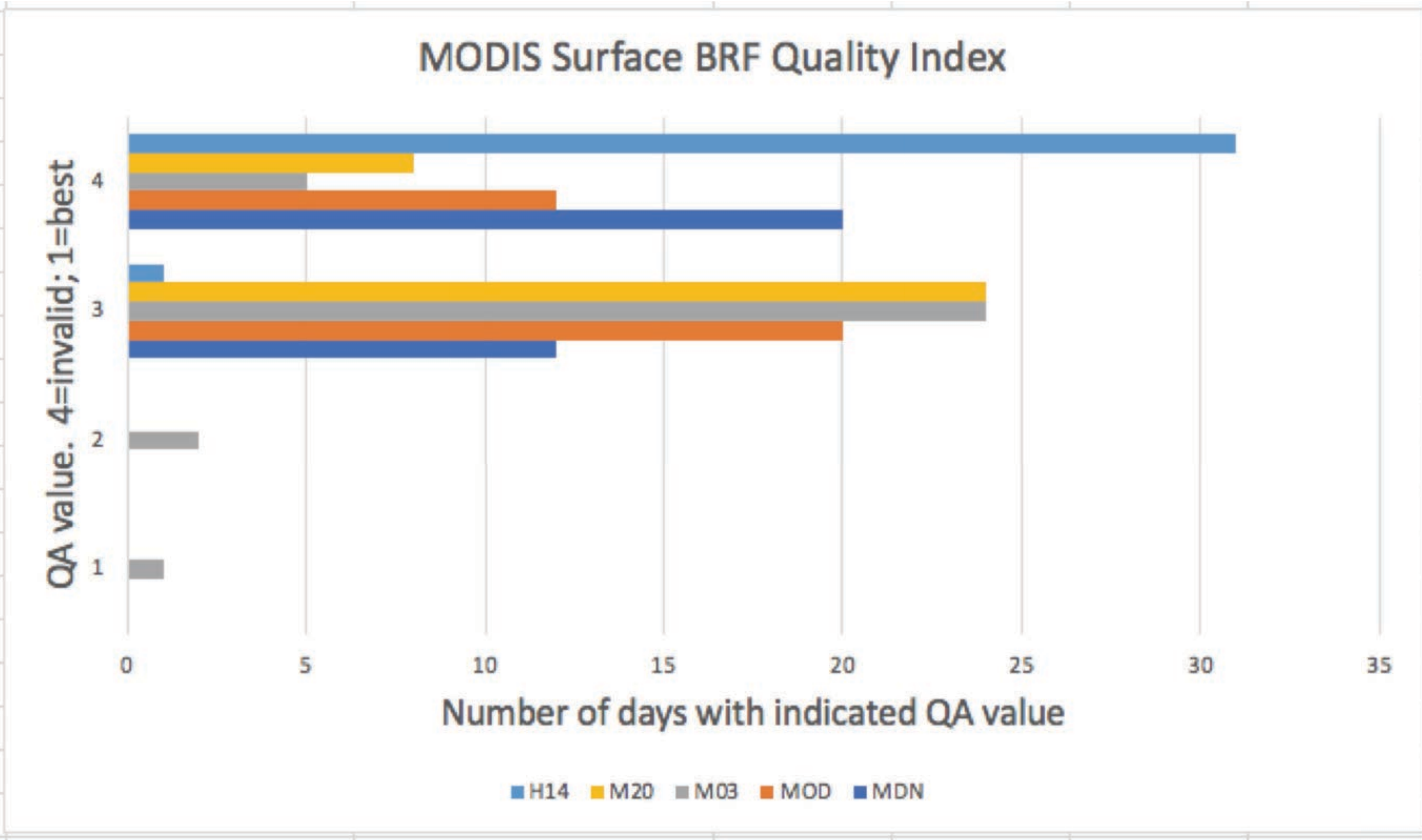
3 = Magnitude inversion (numobs >=2&<7)

4 = Fill value

RRV collects

- 32 overpass dates were investigated, all associated with clear-sky OCO-2 collects.
  - H14 reports invalid data for all but 1 overpass date
  - Sites M03 and M20 have valid data for only 20% of the dates

Frequency of valid MCD43A1



Relaxed aerosol threshold parameter

- On 18Mar2019, Arthur Elmes (post doc in Crystal Schaaf's lab) processed the 30Jun2018 MODIS BRF tile, at my request.
  - Aerosol range relaxed, allowing more days to be used in retrieval

- Reasonable BRF values were obtained for GOSAT Path 36, with QA=0 for all 4 test sites

Solar zen: 20., Solar az: 230., View zen: 20., View az: 90.

Test site	QA	normBRF (SWIR)
MOD	0	0.922
M03	0	0.927
M20	0	0.921
H14	0	0.931

What's next?

mRPV fit

- I would like to fit the normBRF 30Jun2018 MDN PARABOLA data to the mRPV functional form.
  – The normBRF functions is assumed to be spectrally invariant
  – The coefficients can be used to compute normBRF for any arbitrary sun and view geometry
  – Can validate against 03May2018 and ULGS-2 data
  – Coefficients can be posted to the RadCalNet portal, along with information on how to retrieve normBRF from MODIS and MISR.

Timeline

- Would need to finish by end of May
  - RRV campaign in June (see Backup slide)
  - MAIA TVAC fall/ winter

Conclusions

- Surface BRF at RRV changes with soil moisture and surface hardness
- Can vary year-to-year, following winter snow pack melt
- Satellite data offer the capability to retrieve for a specific site and overpass date/ time
  - VIIRS standard data product may be better suited to RRV applications, as compared to MODIS
- In-situ surface measements are important validation data sets for the satellite data

BACKUP SLIDES

Upcoming JPL field campaigns

MISR Path 40 & OCO Path 138 overpass dates

- MISR is on Day 1, followed by OCO the next day
- Path 40 and Path 138 are near-nadir overpasses for MISR and OCO-2, respectively
  - Saturday & Sunday, April 13 & 14
    - Backup dates Monday & Tuesday, April 29 & 30
  - Sunday & Monday, June 16 & 17
  - June 30-July 5
    - Joint OCO-2 & GOSAT team annual campaign
    - Daily PARABOLA setup
    - Tuesday & Wednesday, July 2 & 3 MISR/ OCO dates
  - Fall campaign, Saturday & Sunday, August 3 & 4

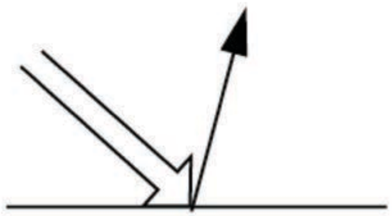
References

- Carol J. Bruegge, Mark C. Helmlinger, James E. Conel, Barbara J. Gaitley & Wedad A. Abdou (2000) PARABOLA III: A sphere-scanning radiometer for field determination of surface anisotropic reflectance functions, Remote Sensing Reviews, 19:1-4, 75-94, DOI: 10.1080/02757250009532411

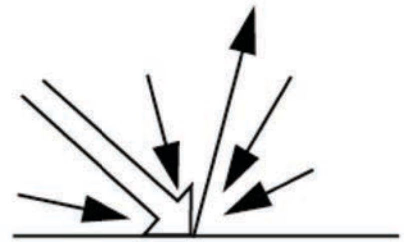
- Carol J. Bruegge, David Crisp, Mark C. Helmlinger, Fumie Kataoka, Akihiko Kuze, Richard A. Lee, James L. McDuffie, Robert A. Rosenberg, Florian M. Schwandner, Kei Shiomi, and Shanshan Yu., "Vicarious Calibration of Orbiting Carbon Observatory-2 (OCO-2)," IEEE Trans. Geosci. and Remote Sens., pp 1-11, early access publication March 20, 2019, **DOI:** 10.1109/TGRS.2019.2897068

- Yufang Jin, Feng Gao, Crystal B. Schaaf, Xiaowen Li, Alan H. Strahler, Carol J. Bruegge, John V. Martonchik, "Improving MODIS surface BRDF/ Albedo retrieval with MISR multiangle Observatoins," IEEE Trans. Geosci. and Remote Sens., pp. 1593-1604, 40(7), July 2002, DOI:10.1109/TGRS.2002.801145

"Reflectance" terminology



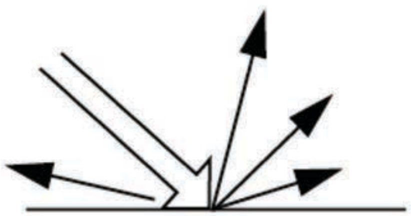
BRF, BRDF



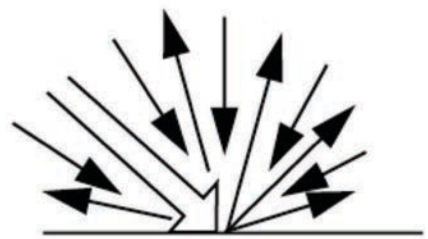
HDRF

Bidirectional reflectance factor, BRF
Bidirectional reflectance distribution function, BRDF
Property of the surface alone

Hemispherical-directional reflectance factor, HRDF
Property of the surface and atmosphere



DHR



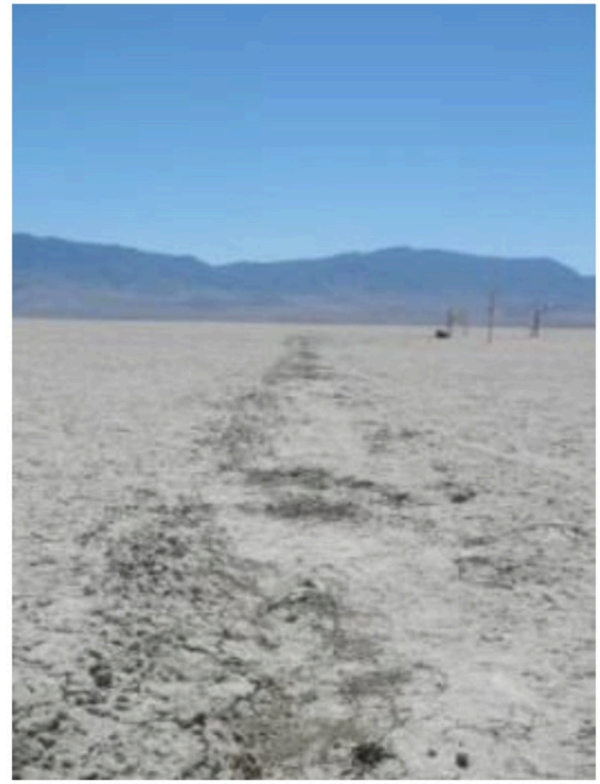
BHR

Directional-hemispherical reflectance, DHR
Black-sky albedo

Bihemispherical reflectance, BHR, or albedo
White-sky albedo if isotropic illumination

The broad arrows represent an irradiance from a collimated beam. All other arrows represent incident and reflected radiance fields.

MODIS site : White, softy and dry-cracking surface.

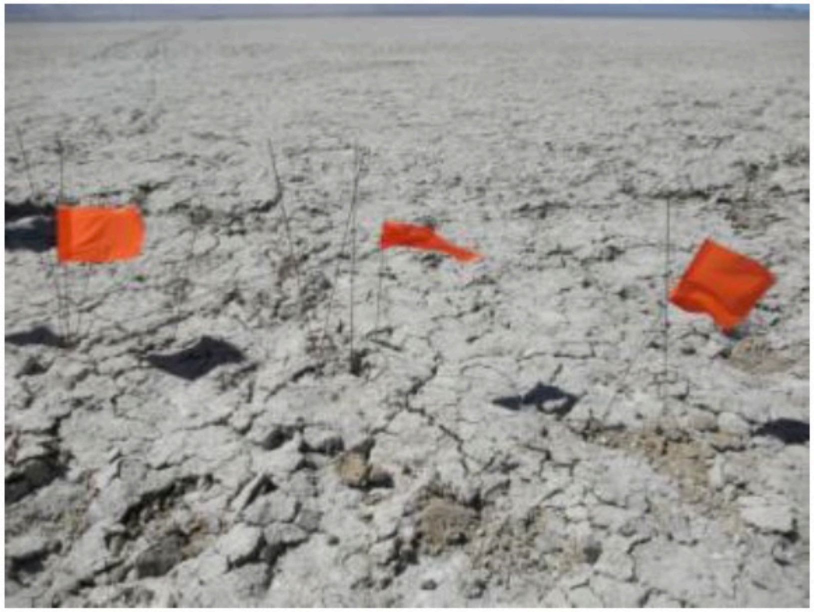


38.49271N ,115.69001W

38.49271N ,115.68891W

M_03 site condition : White, softy and dry-cracking surface.
*permanent site.

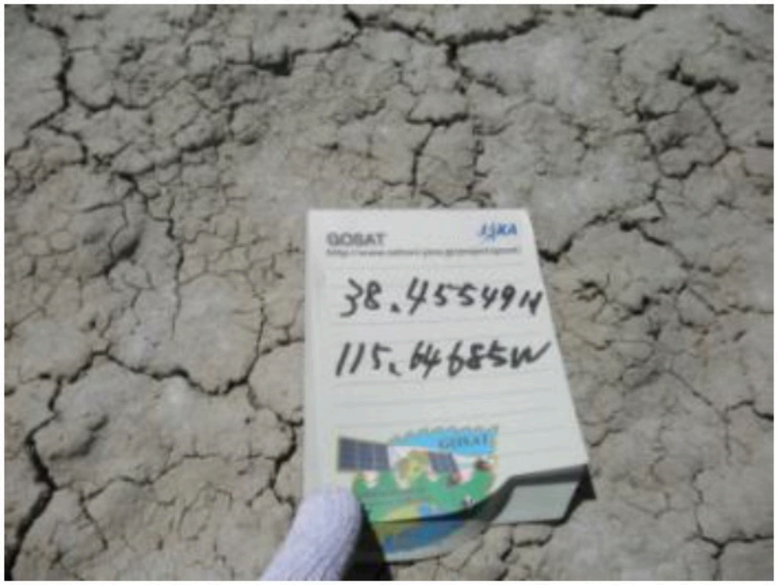
38.48180N ,115.68238W



38.48337N ,115.68812W

M_20 site condition : White, slightly hard and dry- cracking surface.

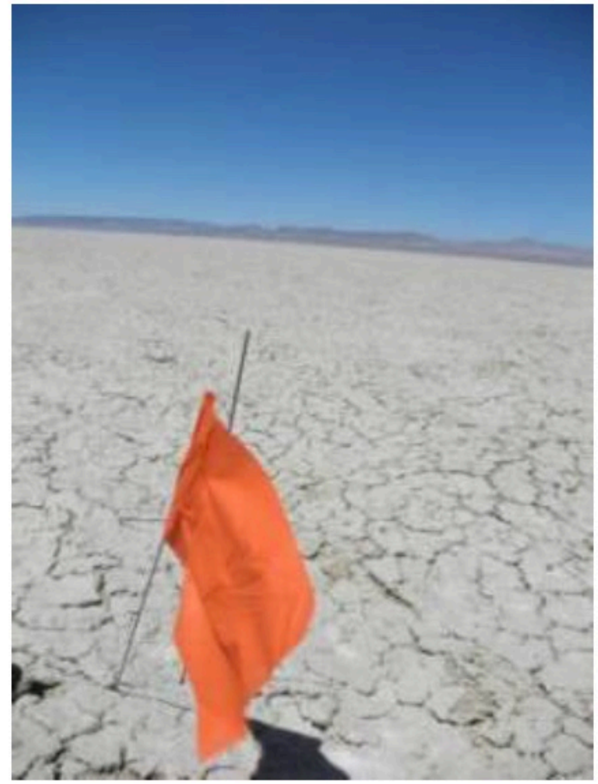
38.45549 ,115.64685W



38.450983N ,115. 641081 W

H_14 site condition : White, hard , some salty and dry- cracking surface.

38.4376N ,115.6658W

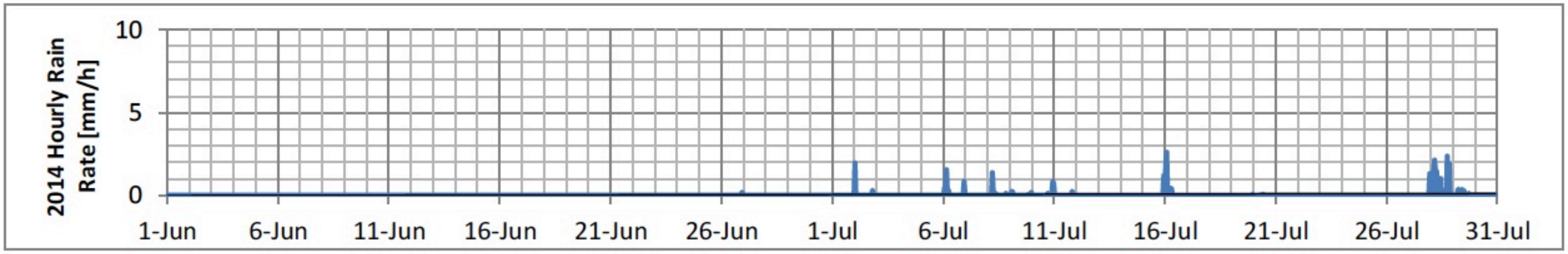


38.4421N ,115.67158W

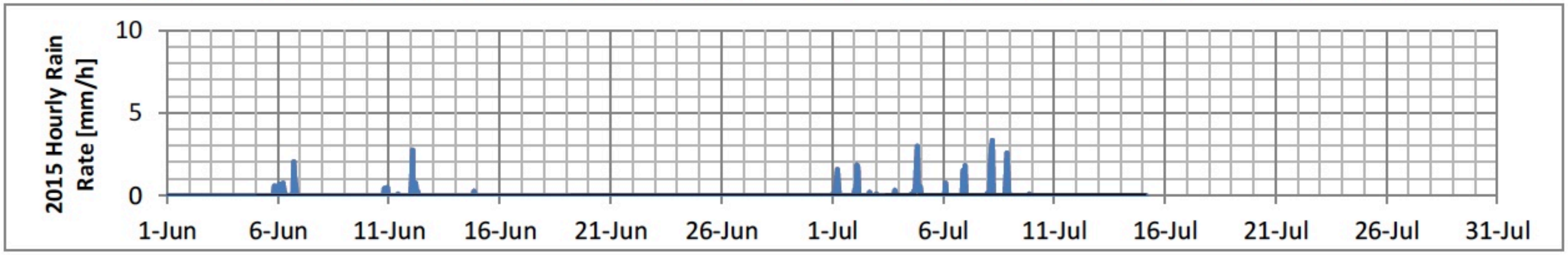
Rainfall in RRV

https://sharaku.eorc.jaxa.jp/GSMaP/index.htm

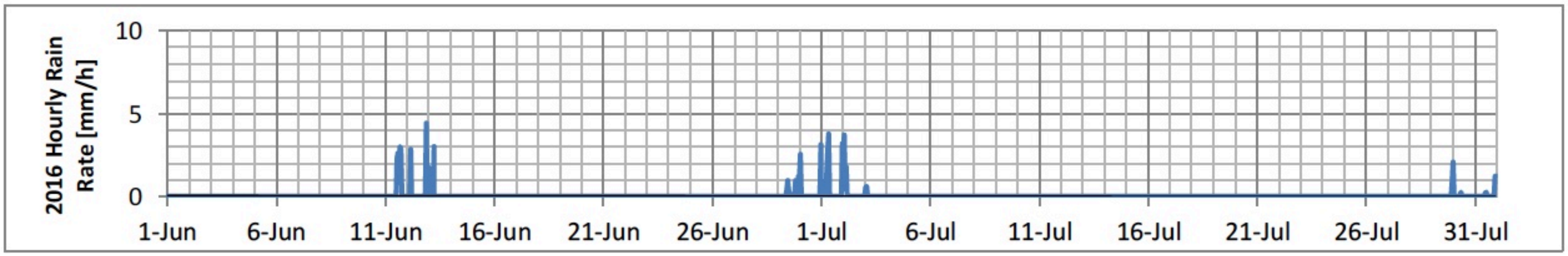
2014
Jun-Jul



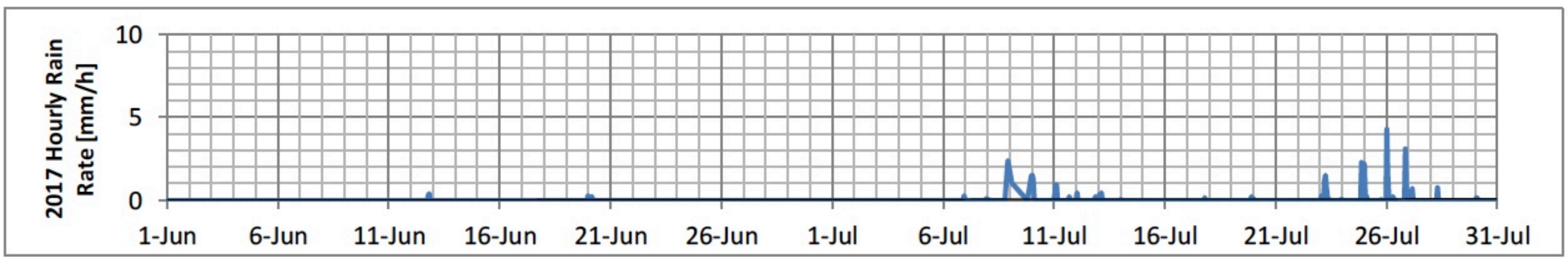
2015
Jun-Jul



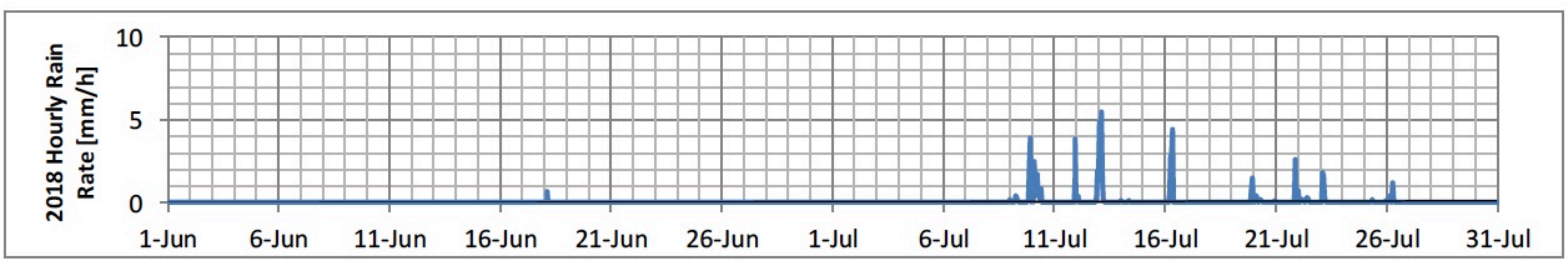
2016
Jun-Jul



2017
Jun-Jul



2018
Jun-Jul



Terminology, cont.

Bi-directional reflectance distribution function (BRDF)

- Ratio of the upwelling radiance to the incident irradiance
- Not unitless
- Not directly measurable, for terrestrial surfaces, due to atmosphere, size of solar disk, finite solid angle

$$\mathrm{BRDF}_r(\theta_i, \phi_i; \theta_r, \phi_r) = \frac{dL_r(\theta_i, \phi_i; \theta_r, \phi_r)}{dE_i(\theta_i, \phi_i)} \quad (\mathrm{sr}^{-1})$$

Bidirectional reflectance factor (BRF)

- Reflected radiance ratioed to that from an ideal surface (non-absorbing, non-transmitting Lambertian surface) under the same illumination and viewing conditions
- Unitless
- Not directly measurable for terrestrial surfaces, but derived from the HDRF if the atmosphere is known
- Equal to $\pi \cdot$ BRDF, since the BRDF of a Lambertian surface is $1/\pi$
- Noting that "reflectance" is ambiguous, one can assume the author is referring to BRF, unless noted otherwise

Terminology, cont.

$$\mathrm{BRF}_r(\theta_i, \phi_i; \theta_r, \phi_r) = \frac{dE_i(\theta_i, \phi_i)}{dL_r^{\mathrm{lam}}(\theta_i, \phi_i)} \cdot \frac{dL_r(\theta_i, \phi_i; \theta_r, \phi_r)}{dE_i(\theta_i, \phi_i)}$$

$$= \pi \cdot \mathrm{BRDF}_r(\theta_i, \phi_i; \theta_r, \phi_r)$$

Strictly speaking, I am reporting HDRF from these RRV in-situ measurements, since have not removed effects of diffuse illumination. "BRF" and "HDRF" are used interchangeably in this presentation; they are approximately equal for these low-aerosol atmospheres.

- Slide 3 introduced an off-nadir correction term which is used to adjust the measured BRF taken with a nadir-viewing instrument. I refer to this function as "normBRF"

$$\mathrm{normBRF} = \mathrm{BRF}(\theta sza, \phi sza \,;\, \theta sza, \phi sza) / \mathrm{BRF}(\theta sza, \phi sza\ 0^{\circ}, 0^{\circ})$$

(Spectral) Albedo

BiHemispherical Reflectance (BHR), or albedo

- Ratio of reflected exitance into a hemisphere to the total incident irradiance
- Not a property of the surface only; depends on illumination conditions
- “white sky albedo” refers to isotropic sky illumination

$$A_{BHR} = \frac{\Phi_r}{\Phi_i} = \frac{dS \int_{2\pi} L_r(\theta_r, \phi_r) \cos\theta_r \sin\theta_r \, d\theta_r \, d\phi_r}{dS \int_{2\pi} L_i(\theta_i, \phi_i) \cos\theta_i \sin\theta_i \, d\theta_i \, d\phi_i}$$